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ORIGINAL RESEARCH

LOWER QUARTER- AND UPPER QUARTER Y BALANCE TESTS AS PREDICTORS OF RUNNING-RELATED INJURIES IN HIGH SCHOOL CROSS-COUNTRY RUNNERS

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ABSTRACT

Background: While cross-country running is a popular interscholastic sport, it also has a high incidence of running-related injuries (RRIs). Recent literature suggests that functional tests may identify athletes at increased risk of injury. The Y-Balance Test (YBT) is an objective measure used to assess functional muscle strength, balance, and expose asymmetries between tested limbs.

Purpose/Hypothesis: The purpose of this study was to determine if the YBT could predict RRI in high school cross-country runners. It was hypothesized that an asymmetric right (R)/left (L) YBT reach distance for the lower or upper extremities would be associated with an increased risk of RRI.

Study Design: Prospective observational cohort

Methods: One hundred forty-eight athletes (80 girls, 68 boys) who competed in interscholastic cross-country in Southern California during the 2015 season participated in the study. Prior to the cross-country season, the runners completed Lower-Quarter YBT (LQ-YBT) and Upper-Quarter YBT (UQ-YBT) testing to assess lower and upper extremity asymmetry, respectively. The runners were prospectively monitored for RRI occurrence throughout the season using the Daily Injury Report form.

Results: Forty-nine runners (33.1%) incurred a RRI during the 2015 season, with the lower leg (shin/calf) and knee the most common RRI sites. Girls had a higher RRI occurrence (38.8%) than boys (26.5%) ($p=0.12$). Boys had greater raw scores for LQ-YBT R and L anterior (ANT), posteromedial (PM), posterolateral (PM) and composite reach distances than girls ($p \leq 0.05$). With the exception of normalized superolateral reach distance, boys had significantly greater scores for raw and normalized R and L UQ-YBT reach distances and raw composite scores than girls ($p \leq 0.05$). After adjusting for prior RRI, while boy runners with a LQ-YBT PM reach difference ≥4.0 cm were five times more likely to incur a RRI (Adjusted odds ratio [AOR] = 5.05, 95% CI: 1.3-19.8; $p=0.02$), girl runners with a UQ-YBT inferolateral (IL) reach difference ≥4.0 cm were 75% less likely to incur a RRI (AOR = 0.25, 95% CI: 0.1-0.7; $p=0.005$). By lower extremity body region, boy runners with a UQ-YBT superolateral (SL) reach difference ≥4.0 cm were seven times more likely to incur a hip/thigh/knee RRI [AOR] = 7.20, 95% CI: 1.1-45.6; $p=0.002$).

Conclusion: Greater lower extremity (PM) or upper extremity (SL) reach distance asymmetry, as measured by the LQ-YBT or UQ-YBT, respectively, were associated with RRI in boy high school cross-country runners.

Level of Evidence: **2b**

Keywords: Asymmetry, cross-country, high school, prospective, running-related injury, Y-Balance Test

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INTRODUCTION

As participation in high school cross-country has become increasingly popular, an incidental increase in running-related injuries (RRIs) has also been observed. Since 1983, a positive trend has been observed in cross-country participation with over 480,000 high school athletes (222,516 girls, 257,691 boys) involved in the sport during the 2015-16 school year.[1] Over one-third of all high school cross-country athletes will sustain a RRI during a sport season, with females consistently incurring an injury more frequently than males.[2-5] The lower-extremity is the most commonly injured body location, with the shin, knee, and ankle the most prevalent sites of RRI for both sexes with few sustaining low back, head, neck, and trunk injuries.[2-5] The cause of RRIs among high school runners is likely multifactorial in nature. Extrinsic factors such as training errors (improper training mileage, variation of distance runs, etc.), irregular terrain, and low step rate may contribute to injury.[4,6-8] Among intrinsic factors, the report of a previous injury has been the most consistently associated factor with musculoskeletal injuries.[5,7-9] An abnormal Q-angle, navicular drop, smaller calf girth, high or low BMI, menstrual irregularity, and low bone mineral density have also been identified as risk factors among high school cross-country runners.[4,5,10-15]

The Y-Balance Test (YBT), based on the Star Excursion Balance Test,[16] is a clinically inexpensive and objective measure used to assess functional lower extremity muscle strength, balance, and expose asymmetries between tested lower limbs that may lead to injury.[17-20] The YBT has been used to assess movement coordination and strength for the upper and lower extremities.[17-27] The lower quarter YBT (LQ-YBT) measures anterior (ANT), posteromedial (PM), and posterolateral (PL) reach distances while the upper quarter YBT (UQ-YBT) assesses medial (MED), inferolateral (IL), and superolateral (SL) reach distances.[16,17] For the lower quarter, a $\geq$4.0 centimeter (cm) reach distance between tested limbs, and composite reach distances less than 94% or less than 89% of the lower limb length have been associated with an increased risk of sport-related injury.[17,21,25] The purpose of the UQ-YBT is to expose asymmetries and imbalances that may significantly impact neuromuscular control of the upper extremities and trunk.[18] Limited evidence is available on the relationship between UQ-YBT scores and sports- or servicemember-related injuries.[27]

As the LQ-YBT incorporates the use of neuromuscular factors such as proprioception, coordination, strength, flexibility, core stability, postural control, and single limb balance, it may be more efficacious than static balance tests previously used, such as postural sway and timed single leg stance in identifying athletes at risk for injury.[20,28,29] Further, as hip muscle weakness has been associated with development of patellofemoral pain syndrome in high school runners, and that a positive relationship between hip muscle strength and LQ-YBT has been observed, the potential use of the LQ-YBT to predict RRI in runners appears plausible.[30,31] Similarly, as the UQ-YBT was developed to identify asymmetries of core stability,[24] and that deficiencies in the core muscles can result in injury in runners,[32] it also appears probable that the UQ-YBT could identify runners at risk of RRI. In a cross-sectional study of 22 injured and 22 matched uninjured male and female runners, Meardon et al. did not find any significant mean differences between the injured and non-injured runners for any of the three SEBT leg-length normalized reach directions.[20] To date, no study has reported the association between LQ-YBT or UQ-YBT scores and RRI exclusively for high school cross-country runners. Therefore, the purpose of this study was to determine if the YBT could predict RRI in high school cross-country runners. It was hypothesized that an asymmetric right (R)/left (L) YBT reach distance for the lower or upper extremities would be associated with an increased risk of RRI.

METHODS

Subjects & Setting

The study prospectively observed male and female high school cross-country runners between the ages of 13 and 19 years of age from four Southern California high schools during the 2015 season. One hundred forty-eight runners (68 males, 80 females) participated in the study. All runners met inclusion criteria, indicating that they were a member of a participating high school cross-country team, and did not have symptoms related to a RRI within two weeks prior to the start of the study. The study was approved by the San Diego State University Institutional Review

Board. Written parental consent and runner assent were provided by all study participants.

Questionnaire
At the beginning of the 2015-2016 cross-country season, each runner completed a pre-season questionnaire providing demographic information, height, weight, and occurrence of RRIs within the prior year.

Lower and Upper Extremity Limb Lengths
Lower and upper limb lengths were measured to normalize LQ-YBT and UQ-YBT scores, respectively. Lower extremity limb length was measured with the runner in supine position on a mat table, from the most inferior aspect of each anterior superior iliac spine to the most distal portion of the medial malleolus, using a cloth tape measure.[16,17] For upper extremity limb length, the participant stood with the arm (being measured) at 90 degrees abduction in the coronal plane and the elbow fully extended. The measurement was taken from the C7 spinous process to the most distal tip of the third phalange using a cloth tape measure.[18]

YBT Protocol
LQ-YBT. The LQ-YBT consisted of unilateral lower extremity reaches in the ANT, PM and PL directions.[16,17] After written instructions were given and the test was demonstrated by one of the instructors, the runners were asked to keep their stance heel down and hands on hips while performing each reach direction with the non-stance leg in socks or barefoot. After a one-minute rest period, the runner completed three formal testing trials for each of the ANT, PM, and PL directions.[16,17] A trial was considered invalid if the runner (1) did not return to starting position, (2) placed the reach foot on the ground, (3) raised or moved the stance foot so that the entire foot did not maintain contact on the platform, (4) placed weight on the reach plate, or (5) kicked the plate with the reach foot.[16,17] Due to the nature of the prospective design to have the runners tested prior to season start, and the time constraints to measure large groups of runners from the teams participating in the study, the runners performed three practice trials on each leg in each of the three reach directions prior to formal testing. During formal testing, runners were allowed four invalid trials before they failed in that reach direction. The greatest reach distance out of three valid trials for each leg in each direction was used for data analysis.

UQ-YBT. Like the protocol for the LQ-YBT, prior to testing, all runners were provided written instructions and then observed a demonstration performed by one of the investigators.[18] In their socks or barefoot, the runners then assumed a pushup position with feet no greater than shoulder width apart. While maintaining the pushup position, the runner used his/her free hand to maximally reach, slowly and under control, in each of three directions MED, IL, and SL in a sequential order without the free hand touching down or runner assuming a resting position.[18] Runners were given three practice trials for each arm prior to formal testing. A trial was discarded and repeated if the runner (1) failed to maintain balance on the stationary hand without touching down between reaches, (2) lifted or moved the balance hand from the platform from the starting position, (3) failed to return the reach hand to the starting point, (4) failed to maintain contact with the sliding target before it came to rest, such as shoving the target instead of maintaining control, or (5) pushed/tapped the plate forward with the reach hand.[18] The best of three valid trials in each direction for each arm was used for analysis.

Reliability of LQ-YBT & UQ-YBT Measures
Prior to the cross-country season, a pilot study was conducted to establish the reliability of the LQ-YBT and UQ-YBT. The intra- and inter-rater reliabilities for all reach directions for the LQ- and UQ- YBT measurements were established using a convenience sample of ten uninjured subjects. The inter-rater intraclass correlation coefficient (ICC 3, 1) for all three directions for both lower and upper extremity measures ranged from 0.99 to 1.00.

Injury Surveillance Protocol
A pre-season meeting was held with each cross-country coach and/or athletic trainer for education and training in the use of the Daily Injury Report (DIR) form.[4,5] The coaches tracked and recorded in the DIR each of their runners' daily participation in practices and-competitive events as well as absences and limitations due to injury. The season started on the first

day of official practice and ended on the last day of regular or postseason competitive event. A running-related injury (RRI) was defined as any reported muscle, bone, or joint problem/injury to the low back or lower extremity (hip, thigh, knee, lower leg [shin, calf], ankle, or foot) that required the runner to be removed from a practice and/or competitive event or miss a subsequent practice and/or competitive event.[4,5] The coaches and/or certified athletic trainers recorded the body part injured and days lost due to the injury, with a day lost defined as any day where the runner did not participate in a practice and/or competitive event without any restrictions. While the coaches and/or athletic trainer were instructed to contact investigators with any questions/issues in reporting injuries, the investigators periodically contacted the coaches/athletic trainers to ask if they had any questions regarding the DIR as well as to ensure that the DIR was being completed on a daily basis.

Data Analysis

Mean and standard deviations of the runners' age, height, weight, and BMI were calculated by sex to document the runner's personal baseline characteristics. Mean baseline measurements for YBT scores, and lower extremity (LE) and upper extremity (UE) limb length measurements were compared by sex using independent t-tests. Since reach distance has been associated with limb length, reach distances were also normalized to limb length and expressed as a percentage by dividing reach distance by limb length and multiplying by 100.[17] Composite reach distance was calculated by the sum of the three reach directions divided by three times the limb length, multiplied by 100.[17] An incidence risk ratio and 95% confidence interval (CI) was calculated to compare RRI risk between sexes.[33] Only the runner's initial RRI was used in all data analyses. For each sex, univariate odds ratios (ORs) with 95% CIs were used to compare initial RRI risks of runners with an asymmetric LQ- or UQ-YBT score, comparing the cumulative initial incidence in an exposed (i.e., asymmetric) group, LQ- or UQ-YBT score, divided by the cumulative incidence in the baseline or referent (i.e., non-asymmetric) group.[33] Univariate ORs and 95% CIs were then calculated to determine if RRI to specific lower body region groups, hip/thigh/knee and lower leg/ankle/foot, were associated with reach direction asymmetry.[20,34] For each direction, ROC analyses were used to determine an appropriate cut-point between right and left reach distance was used to classify a runner as asymmetric. The best cut-off was the same cut-point as reported by Plisky et al., ($\geq$4.0 cm),[17] and therefore was used to assess the injury risk association. Similarly, a cutoff point of $\geq$12.0 cm was used for right to left composite score difference to classify a runner at increased risk of RRI.[17] ROC analyses were used to determine a cut-point for normalized composite score for right and left limbs to classify a runner at increased risk of RRI.[17] Finally, multivariable logistic regression was used to calculate the adjusted ORs (AORs) and 95% CIs to assess the effect of prior RRI on the association between reach direction asymmetry and increased likelihood of RRI.[4,14,17] An alpha level of 0.05 was used for statistical significance for all analyses. All data were analyzed using SPSS for Windows, Version 22 (SPSS Inc., Chicago, IL).

RESULTS

Baseline Characteristics of Runners

At baseline, the average age of the sample was 15.6 years old (Table 1). While boy runners were taller ($p < 0.0001$) and heavier ($p = 0.01$) than girl runners, there was no significant difference in BMI ($p = 0.19$). Of the 148 participants, 67 (45.3%) reported a prior RRI, with girl runners reporting a higher occurrence (64.2%) than boy (35.8%) runners.

The mean limb length, reach distances, reach distances normalized to limb length for the three lower and three upper reach directions, and lower and upper normalized composite reach are presented in Tables 2 and 3, respectively. Boys had significantly greater LQ-YBT raw scores than girls for all three lower reach directions and composite score, but when normalized for lower limb length, no significant differences were found ($p > 0.05$). With exception of the normalized SL reach distance direction, boys had significantly greater UQ-YBT scores than girls for all three raw and normalized reach directions and raw and normalized composite scores.

Running-Related Injuries

Forty-nine (33.1%) of the 148 runners reported a RRI during the 2015 cross-country season. Girls had a higher incidence of RRI (38.8%) than boys (26.5%)

Table 1. *Baseline Characteristics of High School Cross-Country Runners (N = 148).*

	Total		Boys		Girls		
	Mean	SD	Mean	SD	Mean	SD	p-value*
Age (y)	15.6	1.2	15.2	1.2	14.9	1.2	0.20
Height (cm)	167.0	8.5	170.0	8.5	162.7	5.7	<0.001
Weight (kg)	56.6	10.7	59.2	11.7	54.5	9.3	0.01
BMI (kg/m^2)	20.2	3.1	19.8	3.0	20.5	3.1	0.19

SD= Standard deviation; BMI= body mass index.
*Independent *t-test*.

Table 2. *Mean Reach Distance and Limb Length of LQ-YBT of High School Cross-Country Athletes (N = 148).*

	Boys (N=68)		Girls (N=80)		
Variables	Mean	SD	Mean	SD	p-value§
Reach distance					
Anterior (cm)					
R	63.3	7.7	59.4	6.0	0.001
L	64.4	7.6	60.3	6.9	0.001
Posteromedial (cm)					
R	94.1	10.5	88.0	8.7	<0.0001
L	93.2	14.6	88.0	9.5	0.009
Posterolateral (cm)					
R	90.0	10.9	84.7	8.1	0.001
L	89.0	10.3	83.6	10.4	0.002
Composite (cm)*					
R	247.4	25.8	232.5	19.9	<0.0001
L	246.7	27.3	231.8	24.7	<0.001
Limb Length (cm)	89.0	5.2	83.9	4.1	<0.0001
Normalized Reach Distance†					
Anterior (cm)					
R	71.2	7.8	70.9	6.7	0.80
L	72.4	7.7	71.9	7.2	0.70
Posteromedial (cm)					
R	105.8	11.3	105.1	10.6	0.70
L	104.9	16.1	105.0	11.5	1.00
Posterolateral (cm)					
R	101.2	11.8	101.1	10.0	1.00
L	100.2	11.2	99.8	12.8	0.90
Composite (cm)‡					
R	92.7	9.1	92.4	8.0	0.83
L	92.5	9.6	92.2	9.7	0.87

LQ= Lower quarter; R= Right; L= Left

*Sum of the 3 reach distances (anterior, posteromedial, and posterolateral).

†Reach distance divided by limb length multiplied by 100.

‡Sum of the 3 normalized reach distances (anterior, posteromedial, and posterolateral), divided by 3 times limb length, multiplied by 100.

§Independent *t-test*.

(p = 0.12). The lower-leg (38.8%) was the most common site injured followed by the knee (22.4%), and hip/groin (18.4%) (Figure 1). No upper-extremity or trunk RRIs were observed. Overall, no association was found between prior RRI and RRI incurred during the 2015 cross-country season for all runners (p = 0.49); with similar findings for girl (p = 0.50) or boy (p = 0.57) runners.

LQ-YBT and Risk of RRI

After adjusting for prior RRI, boy runners with a LQ-YBT PM reach difference ≥4.0 cm were five times

Table 3. *Mean Reach Distance and Limb Length of UQ-YBT of High School Cross-Country Athletes (N = 148).*

Variables	Boys (N=68) Mean	Boys (N=68) SD	Girls (N=80) Mean	Girls (N=80) SD	p-value§
Reach Distance					
Medial (cm)					
R	79.4	9.1	70.0	7.5	<0.0001
L	79.1	9.0	71.5	7.2	<0.0001
Inferolateral (cm)					
R	78.1	9.4	70.0	8.2	<0.0001
L	78.8	9.8	71.1	7.7	<0.0001
Superolateral (cm)					
R	59.6	10.0	53.5	7.4	<0.0001
L	59.9	9.1	54.6	7.7	<0.0001
Composite (cm)*					
R	217.2	24.3	193.5	18.5	<0.0001
L	217.9	22.5	197.2	17.7	<0.0001
Limb Length (cm)	87.0	4.7	82.0	3.5	<0.0001
Normalized Reach Distance†					
Medial (cm)					
R	91.3	9.2	85.5	9.8	<0.0001
L	90.9	8.8	87.3	9.0	0.02
Inferolateral (cm)					
R	89.7	9.9	85.5	10.3	0.01
L	90.6	11.3	87.3	9.0	0.03
Superolateral (cm)					
R	68.5	10.6	65.4	9.3	0.06
L	68.9	9.9	66.7	9.9	0.20
Composite (cm)‡					
R	83.2	8.2	79.8	8.0	<0.001
L	83.5	7.7	80.3	7.7	<0.01

UQ= Upper quarter; R= Right; L= Left.

*Sum of the 3 reach distances (medial, superolateral, and inferolateral).

†Reach distance divided by limb length multiplied by 100.

‡Sum of the 3 normalized reach distances (medial, superolateral, inferolateral), divided by 3 times limb length, multiplied by 100.

§Independent *t-test*.

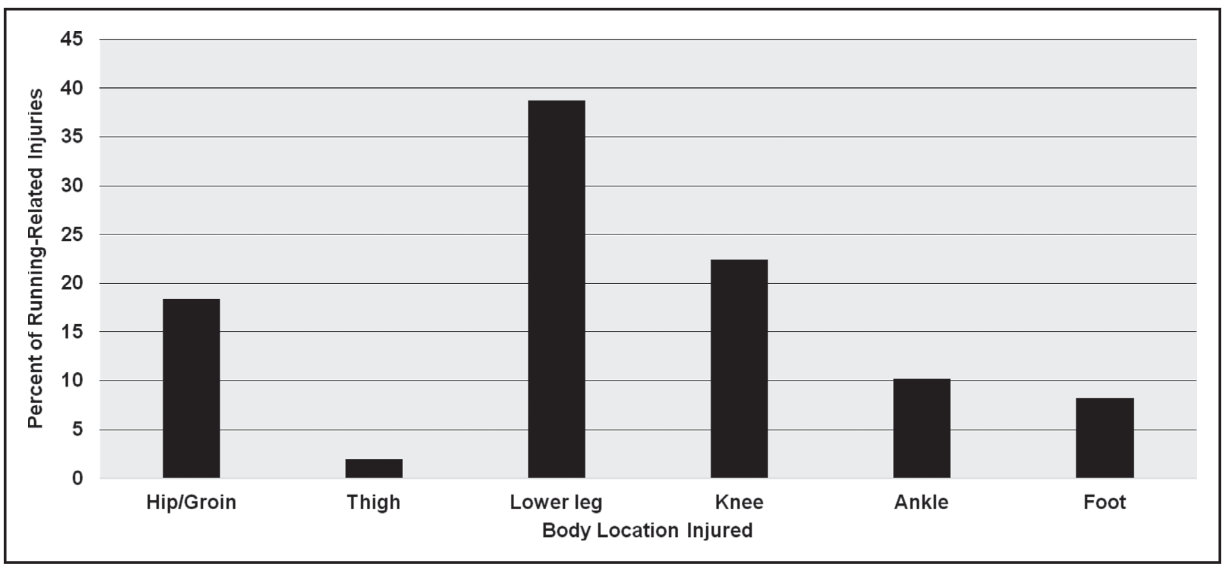

Figure 1. *Cumulative incidence of running-related injury in high school cross-country runners (N = 148).*

more likely to incur a RRI (Adjusted odds ratio [AOR] = 5.05, 95% CI: 1.3-19.8; p = 0.02); no significant associations were found between RRI and LQ-YBT ANT or PL reach direction differences ≥4.0 cm (p > 0.05) (Table 4). None of the three LQ-YBT reach direction differences ≥4.0 cm were associated with RRI for girl runners (p > 0.05). For girl and boy runners, no associations were found between RRI and raw composite difference ≥12.0 cm for the lower quarter or upper quarter, or for normalized right and left composite reach scores for the LQ-YBT.

For both boy and girl runners, no associations were found between lower extremity body region RRI and any LQ-YBT reach direction difference ≥4.0 cm, raw composite or normalized composite score difference asymmetry (p > 0.05).

UQ-YBT and Risk of RRI

After adjusting for prior RRI, girl runners with a UQ-YBT IL reach difference ≥4.0 cm were 75% less likely to incur a RRI (Adjusted odds ratio [AOR] = 0.25, 95% CI: 0.1-0.7; p = 0.005); no significant associations were found between RRI and UQ-YBT MED or SL reach direction differences ≥4.0 cm (Table 5) (p > 0.05). None of the three UQ-YBT reach directions differences ≥4.0 cm were associated with RRI for boy runners (p > 0.05). For girl and boy runners, no associations were found between RRI and raw composite reach difference, or right or left normalized composite UQ-YBT scores (p > 0.05).

Boy runners with a UQ-YBT SL reach difference ≥4.0 cm were seven times more likely to incur a hip/thigh/knee region RRI (AOR = 7.20, 95% CI: 1.1-45.6; p = 0.002). For both boy and girl runners, no other associations were found between lower extremity body region RRI and any UQ-YBT reach direction difference, raw composite or normalized composite score difference (p > 0.05).

DISCUSSION

The primary purpose of this study was to determine if the LQ-YBT or UQ-YBT could predict occurrence of RRIs in high school cross-country runners. Boy runners with a ≥4.0 LQ-YBT PM reach difference had an increased likelihood of any RRI. Similarly, boy runners with a UQ-YBT SL reach difference ≥4.0 cm were more likely to have a hip/thigh/knee injury. Conversely, girl runners with a UQ-YBT IL reach difference ≥4.0 cm were less likely to incur a RRI. No associations were found between RRI and lower extremity body region RRI occurrence during the season and for other LQ-YBT or UQ-YBT reach

Table 4. *Relationship Between Lower Quarter YBT and Running-Related Injury Occurrence for High School Runners (N = 148).*

	Boys (n=68)					Girls (n=80)				
Test/Reach Difference	n at Risk	% RRI	AOR	95% CI	p-value§	n at Risk	% RRI	AOR	95% CI	p-value§
Lower Quarter Reach Difference*										
Anterior										
<4.0	26	30.8	1.00 (ref)			40	42.5	1.00 (ref)		
≥4.0	42	23.8	0.70	0.2-2.1	0.53	40	35.0	0.69	0.3-1.7	0.43
Posteromedial										
<4.0	28	10.7	1.00 (ref)			37	43.2	1.00 (ref)		
≥4.0	40	37.5	**5.05**	**1.3-19.8**	**0.02**	43	34.9	0.71	0.3-1.8	0.46
Posterolateral										
<4.0	40	25.0	1.00 (ref)			55	45.5	1.00 (ref)		
≥4.0	28	28.6	1.28	0.4-3.9	0.66	25	24.0	0.37	0.1-1.1	0.07
Composite Reach Difference†										
<12.0	25	20.9	1.00 (ref)			56	42.9	1.00 (ref)		
≥12.0	43	36.0	2.15	0.7-6.5	0.17	24	29.2	0.52	0.2-1.5	0.22
Normalized Composite Reach‡										
R>105.0	30	26.3	1.00 (ref)			56	41.1	1.00 (ref)		
R≤105.0	38	26.7	1.05	0.4-3.2	0.93	24	33.3	0.67	0.2-1.9	0.44
L>104.0	30	20.0	1.00 (ref)			52	36.5	1.00 (ref)		
L≤104.0	38	31.6	1.95	0.6-6.1	0.25	28	42.9	1.30	0.5-3.3	0.58

RRI= Running-related injury; AOR= Adjusted odds ratio; CI= Confidence Interval; Ref= Reference group.
*Difference between right and left reach distances (cm).
†Sum of the 3 reach distances (anterior, posteromedial and posterolateral).
‡Sum of the 3 normalized reach distances (anterior, posteromedial, and posterolateral), divided by 3 times limb length, multiplied by 100.
§Chi-square test.

Table 5. *Relationship Between Upper Quarter YBT and Running-Related Injury Occurrence for High School Runners (N = 146).*

	Boys (n=68)					Girls (n=78)				
Test/Reach Difference	n at Risk	% RRI	AOR	95% CI	p-value§	n at Risk	% RRI	AOR	95% CI	p-value§
Upper Quarter Reach Difference*										
Medial										
<4.0	41	29.3	1.00 (ref)			42	33.3	1.00 (ref)		
≥4.0	27	22.2	0.68	0.7-1.8	0.50	36	44.4	1.61	0.6-4.1	0.31
Inferolateral										
<4.0	30	20.0	1.00 (ref)			36	55.6	1.00 (ref)		
≥4.0	38	31.6	1.95	0.6-6.1	0.25	42	23.6	**0.25**	**0.1-0.7**	**0.005**
Superolateral										
<4.0	31	22.6	1.00 (ref)			38	36.8	1.00 (ref)		
≥4.0	37	29.7	1.54	0.5-4.7	0.45	40	40.0	1.12	0.5-2.8	0.81
Composite Reach Difference										
<12.0	45	26.7	1.00 (ref)			63	36.5	1.00 (ref)		
≥12.0	23	26.1	1.03	0.3-3.3	0.96	15	46.7	1.52	0.5-4.8	0.47
Normalized Composite Reach										
R>94.0	39	23.1	1.00 (ref)			43	44.2	1.00 (ref)		
R≤94.0	29	31.0	1.50	0.5-4.4	0.47	36	33.3	0.53	0.2-1.4	0.21
L>93.9	39	20.5	1.00 (ref)			44	40.9	1.00 (ref)		
L≤93.9	29	34.5	2.04	0.7-6.1	0.20	35	34.3	0.70	0.3-1.8	0.46

RRI= running-related injury; AOR= Adjusted odds ratio; CI= Confidence Interval; Ref= Reference group.
*Difference between right and left reach distances (cm).
†Sum of the 3 reach distances (medial, superolateral, and inferolateral).
‡Sum of the 3 normalized reach distances (medial, superolateral, and inferolateral), divided by 3 times limb length, multiplied by 100.
§Chi-square test.

direction or composite score asymmetric differences for girls or boy runners.

LQ-YBT & UQ-YBT Values

LQ-YBT. To the authors' knowledge, there are no published reports of LQ-YBT reach or composite score values specific to high school cross-country runners. Plisky et. al. examined lower extremity SEBT (precursor to the YBT) scores among high school basketball players.[17] For all normalized reach directions, the basketball players had higher scores than the runners in the current study. From these results, the authors discern that proximal control and stability may be paramount when performing the YBT.[19,20,35] Runners may have weaker proximal muscles and therefore find it more challenging to balance and control the movements required to perform the YBT.[36] This then suggests that the YBT may have a sport-specific component.[32] Sports that bias quadriceps and gluteal development will likely result in higher YBT scores, as they mimic muscle movements observed during testing.[21,37] Similar to Plisky et al,[17] the girls had lower reach raw scores than boys for the three reach directions. However, when normalized for limb length, few significant differences were found. This suggests normalization of data by limb length is important when comparing reach scores by sex.

UQ-YBT. Similar to the LQ-YBT, to the authors' knowledge, there are no published findings of UQ-YBT reach or composite score values in high school cross-country runners. In the current study, the runners' scores were highest for the MED reach direction and lowest during the SL reach direction. Boys also yielded a greater composite score when compared to girls. Among high school baseball and softball players, Butler et al. reported no statistically significant asymmetrical YBT values between the dominant and non-dominant arm, and also found no statistically significant asymmetrical YBT reach and composite score values between the dominant and non-dominant arm between baseball and softball players.[24] Performance was greatest in the MED reach direction, and the SL direction displayed the poorest performance across gender and extremities. Boys displayed a higher composite score of 87.1 cm compared to girls at 86.3 cm, but this was not statistically significant.[24] Like the current study, they also reported that while girls had lower UQ-YBT scores than boys, the differences were not statistically significant.

YBT and RRI

LQ-YBT. Plisky et. al. found that high school basketball players with a greater ANT right/left reach difference ≥4.0 cm were 2.5 times significantly more likely to incur a lower extremity injury.[17] Several other investigators have also reported that Division I athletes with greater asymmetry (i.e., LQ-YBT ≥4.0 cm) in the ANT reach direction indicated a higher predisposition for injury.[25,38,] Unlike these prior studies, in the current study, the ANT reach direction asymmetry was not associated with RRI. Further, only boy runners with a PM reach direction difference ≥4.0 cm were significantly more likely to incur a RRI. Unlike Plisky et al., no reach directions ≥4.0 cm were associated with an increased likelihood of RRI for girl runners. In fact, all reach direction asymmetries demonstrated a protective effect rather than an increased risk pattern. As this is the first study to report these associations with LQ-YBT reach direction and injuries among high school runners or any other running population, to the authors' knowledge, they cannot confirm if these patterns are consistent or dissimilar among runners. Further, while the reasons for these protective effect patterns among the girl runners are not clear, the authors speculate that the LQ-YBT might not be an appropriate tool for predicting RRI in girl high school runners. Poor movement quality in running, especially frontal plane movements such as repetitive knee valgus during loading is detrimental to the health condition and frequently contributes to injuries such as patellofemoral pain syndrome and osteoarthritis.[39,40] However, the LQ-YBT does not have a frontal plane measure and as a result, qualitative measures such as knee valgus are not being identified during testing. The current LQ-YBT protocol does not prohibit any excessive lower limb movement (particularly valgus) in any of the three planes of movement as long as the athlete maintains balanced or does not commit a testing error. While the excessive movement in the frontal plane may be allowable due to the dynamic nature in many ball sports, this excessive movement would be considered abnormal in running biomechanics. Thus, a runner with actual greater asymmetry in the frontal plane, and therefore at risk for RRI, might demonstrate higher, symmetrical reach distances obtained due to poor body mechanics; thus decreasing the true risk association. These movements were observed on many occasions but was not noted for comparisons between the sexes. Future studies are needed to determine frontal plane sensitivity of the LQ-YBT with controlled and uncontrolled movement in the frontal plane of the stance leg. It is possible by improving sensitivity in the frontal plane and limiting the amount of movements such as knee varus and valgus, a more accurate evaluation of asymmetry may be found and a more true injury risk association observed.

UQ-YBT. In this study, while no UQ-YBT reach direction or composite score asymmetry was associated with increased likelihood of any RRI, when examined by lower extremity body region, boy runners with a SL reach direction difference ≥4.0 cm were more likely to incur a RRI to the hip/thigh/knee region. This finding seems plausible as the SL reach may create more stress to "core" or proximal lower extremity muscles like the hip, thigh or knee as it places the runner in a "plank-like" position. As the UQ-YBT is thought to expose asymmetries and imbalances that may significantly impact neuromuscular control of the upper extremities and trunk,[18] the SL reach may help to better identify RRIs to the hip, thigh or knee that are more proximal. Some caution is advised, however, when interpreting the statistical (95% confidence interval was fairly wide indicating limited precision of the association) and clinical significance of this finding as they are based on a smaller group of runners with a SL reach difference asymmetry and hip/thigh/knee region RRI. Different from the boy runners, however, girl runners who had an IL reach difference ≥4.0 cm were significantly less likely to sustain a RRI during the season. The reason(s) for this unexpected finding are not clear. One explanation may be that the IL reach may allow more opportunities for uncontrolled or relatively unnatural trunk flexion movements that may increase the possibility for the association between IL reach and RRI to be a spurious or artifactual finding. Like the LQ-YBT for female runners, more studies are needed to determine if this finding was indeed an artifact. Ideally, that would include assessment of the quality of movement, rather than allowing the runner to move him/herself in any position to get the best reach distance, and may help to better understand the true association. Like the LQ-YBT, to the authors' knowledge, there have not been any prior reports on the relationship between UQ-YBT and RRI among high school runners for comparison. Prior studies, including those conducted by Butler et al. examining high school baseball and softball players, as well as collegiate swimmers, have observed inconclusive results as well.[23,24] Thus, as there is such limited evidence on injury and UQ-YBT scores, future studies should examine the association between asymmetrical scores and injury occurrence.

Strengths

In the pilot study, the intra- and inter-rater reliabilities for all LQ- and UQ- YBT reach direction measurements ranged from 0.99 to 1.00, indicating that with appropriate training the testers in this study were highly consistent with little error. The high reliability estimates are consistent with those reported in other high school sports,[16-18] and increased the confidence of the reach direction measurements recorded for the main study. Second, a prospective cohort design was used, allowing establishment for baseline functional characteristics prior to testing. All runners were uninjured at the time of testing, thus minimizing researcher bias during data collection. Third, this study followed a structured sequence and all participating runners were trained in the testing procedure, which helped reduce testing errors. Finally, this study may be the first to report simultaneous examination of both the LQ-YBT and UQ-YBT and their relationship to injury in any sport at any level.

Limitations

Several limitations in this study are noteworthy. First, although the sample size was relatively large to examine the primary hypotheses for any RRI, it did not allow for adequate assessment of specific injuries by body location. Thus, specific body locations were lumped into a proximal or distal body region for examination to gain a better understanding of the risk relationship between LQ-YBT or UQ-YBT reach direction or composite scores. While the association between SL reach and hip/thigh/knee region was found, there is still some over-generalization of the RRI as the association is not based on a specific body location/part injured. Thus, the authors highly recommend that future studies should be designed to study a large enough sample size of high school runners that will capture the necessary number of the specific RRI type (e.g., MTSS) to assess the associations between that specific RRI and LQ- or UQ-YBT. Second, it is likely that some injuries were not reported in the DIR as some runners may have felt that reporting their RRI might result in them not being allowed to run in a practice or competitive event. Consequently, this may have partially affected the true relationship between asymmetry and likelihood of RRI. Finally, the commonly used number of practice tests for the LQ-YBT and UQ-YBT were reduced from 4-6 to three due to the time constraints to testing a large number of runners prospectively prior to the season. The effect that this may have had on the runner's final testing is unknown. It is possible that the common method of six practice trials might not be representative of the movement patterns present with the repetitive demands of distance running. Future studies may want to consider having the runner run for a certain distance or time to fatigue the muscles prior to performing the tests.

Future Directions

To better examine the predictability of future RRI using the LQ-YBT or UQ-YBT, future studies should strive to obtain larger sample sizes of high school runners, which would allow for examining relationships with specific running-related injuries as well as provide a more representative sample of YBT performance among runners. It is recommended that future studies incorporate a qualitative aspect while assessing YBT performance, rather than only assessing maximum reach direction scores. Furthermore, movement patterns specific to running mechanics should be observed so that abnormal motion can be identified and screened. Lastly, while the ROC analyses indicated that a cut-point of $\geq$4.0 cm classified a runner at increased risk for RRI, this cut-point might vary in different running populations. Thus, future studies should continue assessing if a larger or smaller cut-point might better identify runners at increased risk for RRI.

CONCLUSIONS

The results of this study indicate that boy runners with a ≥4.0 LQ-YBT PM reach difference had an increased likelihood of any RRI, and boy runners with a UQ-YBT SL reach difference ≥4.0 cm were more likely to have a hip/thigh/knee injury. Conversely, girl runners with a UQ-YBT IL reach difference ≥4.0 cm were less likely to incur a RRI. No associations were found between RRI and lower extremity body region RRI occurrence during the season and for other LQ-YBT or UQ-YBT reach direction or composite score asymmetric differences for girls or boy runners. These results partially supported the hypotheses that greater asymmetry, as measured by LQ- or UQ-YBT right-left reach direction difference asymmetries (PM and SL, respectively), would be associated with greater risk of RRI in high school cross-country runners; however, this was observed in boys only.

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